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LIGHTNING FATALITIES, INJURIES AND DAMAGE REPORTS IN THE UNITED STATES, 1959 -1994

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ABSTRACT

Lightning-related fatality, injury, and damage reports in the US were summarized for 36 years since 1959, based on the NOAA publication *Storm Data*. There were 3239 deaths, 9818 injuries, and 19,814 property-damage reports from lightning during this period. The number of lightning-caused casualty and damage events was less variable from year to year than other weather causes. For this reason, lightning is the most constant and widespread threat to people and property during the thunderstorm season.

By state, Florida led the nation in the actual number of deaths and injuries, while the largest number of damage reports came from Pennsylvania. There were large variations among decades in casualties and damages. When population was taken into account, New Mexico (all decades) and Wyoming (mainly in the 1960s and 1970s) led the nation in death, injury, and casualty rates. High casualty rates tended to be in Florida, the Rocky Mountains, plains, southeast, and New England. The highest rates of population-weighted damage reports were on the plains.

By month, all types of lightning reports in *Storm Data* reached maxima during July. Damage reports were spread more evenly through the year than were casualties. Casualties and damages in northern regions of the US had narrower distributions centered on summer than southern regions.

Within the day, two-thirds of the casualties occurred between noon and 6 p.m. There were relatively frequent damage reports during the night in the plains and midwest states. In winter, the afternoon peak disappeared for damage reports and was weak for casualties. Casualties were most frequent on Sunday, the next most common day was Saturday, then Wednesday. Damage reports were most frequent on Monday, then decreased on nearly every day until reaching the lowest number on Saturday.

Most incidents involved one person. For incidents involving deaths only, 91% of the cases had one fatality, while another 8% of the events had two people killed in the same incident. For incidents involving injuries only, 68% of the cases had one injury; casualties clustered nearly the same as injuries. Males were killed by lightning 5.6 times as often as females, and were 4.9 times as likely to be injured as females.

The digital *Storm Data* listing of the locations of victims is not very precise. Of the known locations, recreation was the largest category in every region and in the US. The next largest group involved people located under trees, and the next was related to the proximity to bodies of water. The remaining categories involving small numbers of people were golfers, people involved in agricultural activities, telephones users, and people in proximity to radios and antennas.

Half of all lightning-caused damage costs were between $5,000 and $50,000 according to *Storm Data*. Comparison with other datasets shows that *Storm Data* entries tend to include more expensive widely-known events and to exclude most of the small losses.

1. INTRODUCTION

This report summarizes casualties and damages from lightning in the United States. The information comes entirely from the National Oceanic and Atmospheric Administration (NOAA) publication *Storm Data*. Features of the national distribution of lightning-caused casualties have been summarized in a variety of ways in previous publications that will be referenced in this paper. These studies include Zegel (1967), Weigel (1976), Mogil et al. (1977), Vigansky (1985), Duclos and Sanderson (1990), Duclos et al. (1990), and López and Holle (1995, 1996). Studies have also been made of lightning casualties and damages in Michigan (Ferrett and Ojala, 1992), central Florida (Holle et al., 1992), Colorado (López et al., 1995), and Rocky Mountain states (Holle et al., 1996).

Short summaries of weather impacts based on *Storm Data* have been published each year since 1990 by the Office of Meteorology in NOAA's National Weather Service. From the 1992 to 1994 summaries, Table 1 shows the average number of deaths in the United States due to four categories of thunderstorm-related weather events. During this three-year period, lightning caused 44% of the fatalities, 19% of the injuries, and 3% of the damages for all convective-weather reports in *Storm Data*. Absolute values of these numbers must be considered with caution, for reasons given in the next chapter.

When all types of weather-related casualties are examined, Table 2 shows that lightning remains near the top of the list; only flash floods and river floods combined rank higher than lightning in terms of deaths. There is a substantial number of lightning victims and damages every year. Lightning entries have the least year-to-year variability of all convective-weather causes in Table 1, and less variability than nearly all other phenomena in Table 2. The result is that the vulnerability to lightning is a constant and widespread threat to people and property during every thunderstorm season. A somewhat similar study by Dittmann (1994) used *Storm Data* to examine state-by-state flood deaths from 1959-1991.

The need for the current study and other recent examinations of lightning victims was emphasized by Emanuel et al. (1995) who stated:

> "We believe that it is time to perform an analysis of the type of electrical storms that kill people" (page 1201).

It should be mentioned that a renewed interest in medical issues concerning lightning casualties has occurred. Recent publications on lightning-related deaths and injuries include a book by Andrews et al. (1992), two 1995 issues of *Seminars in Neurology*, and numerous articles such as those by Cherington (1995), Cooper (1995), and Cooper and Andrews (1995).

TABLE 1. Annual averages of casualties and property damage due to convective weather (thunderstorms) during 1992-1994 (from National Weather Service, Office of Meteorology). Order is by number of deaths per year.

Convective weather type	Fatalities	Injuries	Damage ($millions)
Lightning	51	345	32
Tornadoes	47	1114	551
Thunderstorm wind	18	352	192
Hail	0	21	345

TABLE 2. Summary of 1994 weather casualties, and 30-year normals (from National Weather Service, Office of Meteorology). Order is by 30-year death rate, then by 1994 deaths.

Weather type	1994 deaths	1994 injuries	Deaths per year
Flash flood	59	33	} 139
River flood	32	14	
Lightning	69	484	87
Tornado	69	1067	82
Hurricane	9	45	27
Extreme temperatures	81	298	
Winter weather	31	2690	
Thunderstorm wind	17	315	
Other high wind	12	61	
Fog	3	99	
Other	6	59	
Total	388	5,165	

2. LIGHTNING REPORT DATA

Reports of damaging weather phenomena are collected monthly by local NOAA-National Weather Service offices. Individual station reports are sent to NOAA's National Climatic Data Center (NCDC) in Asheville, N.C. where *Storm Data* is assembled for the entire country. This publication has been compiled with essentially the same procedures and agencies since 1959.

The database used in this study contains all reports published in *Storm Data*. Each report contains the following information:

- Year, month, and day.
- Time in Local Standard Time (LST).
- State and county.
- Number of fatalities.
- Gender and location of fatalities.
- Number of injuries.
- Gender and location of injuries.
- Categorical amount of damage reported.

The total number of lightning-caused reports in the *Storm Data* archive during the 36 years is in Table 3. A total of 11 casualty or property-damage reports were found to be assigned to the wrong state in the digital database by cross-checking them with the two-letter state codes. The quality of the NCDC database, defined as the ratio of incidents with known time and date of occurrence to all incidents, has improved from below 40% during the 1960s to above 90% after 1987.

TABLE 3. Total lightning-related reports in *Storm Data* from 1959-1994.

Impacts	Entries
Deaths	3,239
Injuries	9,818
Casualties (deaths and injuries combined)	13,057
Property damage	19,814

Absolute values of the casualties and especially damages in Tables 1 to 3 must be considered with caution. Lightning-caused casualty and damage events are usually less spectacular and more widely dispersed in time and space than are other weather phenomena such as tornadoes and hurricanes. For this reason, lightning deaths, injuries, and damages are underreported, as found in the following studies:

* Mogil et al. (1977) found 33% more lightning deaths in Texas than *Storm Data*.
* López et al. (1993) found 28% more fatalities and 42% more injuries requiring hospitalization in Colorado than *Storm Data*.
* Holle et al. (1996) found 367 times as many insured personal property claims due to lightning in three western states than were listed during the same years in *Storm Data*.
* Lushine (1996) found 31% more fatalities in Florida than *Storm Data*.

The results of Holle et al. (1996) lead to the conclusion that lightning-caused losses are similar to, or exceed other phenomena in Table 1. When other unquantified losses are taken into account, lightning may be the largest cause of damages and have less change from year to year than most other weather types.

Factors contributing to underreporting include the following:

- Indirect lightning casualties are often reported by the medical system as having lightning as the secondary rather than the primary cause (Mogil et al., 1977).
- Reliance on newspaper clipping services for lightning events entered in *Storm Data* by the National Weather Service (López et al., 1993).
- The typical lightning casualty usually affects only one individual.

However, the only consistent source of data on lightning deaths, injuries, and damages for several recent decades has been *Storm Data*. With the exception of 106 damage entries that were miscoded in the year 1989 (Section 12), the *Storm Data* information will be used in the present report without modification.

3. VARIATIONS BY STATE IN REPORTED FREQUENCIES

A. DEATHS AND INJURIES COMBINED (CASUALTIES)

Section 3 describes variations among states in actual frequencies of lightning reports by the use of maps and tables. This section shows results without population weighting; population is included in section 4. Data used to develop the following maps and tables are given at the end of section 3.

The sum of fatalities and injuries together is termed casualties. Figures 1 and 2 map the sum of lightning-caused deaths and injuries. Tables 4 and 5 give the top and bottom ten locations for deaths and injuries combined. All states are shown in descending order by the number of casualties in Figure 3. The largest numbers of casualties are in Florida, Michigan, Pennsylvania, North Carolina, and New York. Other high numbers are found in the southern and eastern regions of the US, and some states in the northeastern US where there is a large population. Also evident is a large number of casualties in the mountainous, dry states of Colorado, New Mexico, and Arizona. The smallest numbers of lightning casualties are in Alaska (none), Hawaii, the District of Columbia, northwest US states, Puerto Rico, and several small eastern states. Casualties by county for Colorado are in López et al. (1995).

There are 13,057 *Storm Data* casualties from 1959 to 1994 (Table 3 and Figures 1 to 3) for an average of 363 per year. The National Lightning Detection Network identified an average of 21,746,000 cloud-to-ground flashes per year in the US from 1992 to 1995 (Orville and Silver, 1997). Assuming this four-year average to be representative, the result is a casualty every 60,000 flashes. Since around 70% of the flashes were detected, about 86,000 flashes occur for each casualty. A similar estimate can be made for Arizona from López et al. (1997). Making corrections for season, analysis area, and detection efficiency, about 800,000 flashes per year occur in Arizona, while there were 4.5 casualties per year from 1959-1994 (Table 12). The resulting ratio in Arizona is one casualty for every 175,000 flashes; this is reasonable since there usually are fewer flashes in Arizona than in the rest of the US (Orville, 1991; Orville and Silver, 1997).

TABLE 4. Ten US locations with the most casualties (deaths and injuries combined) due to lightning from 1959-1994 in *Storm Data.*

Rank	State	No. of deaths and injuries
1	Florida	1523
2	Michigan	732
3	Pennsylvania	644
4	North Carolina	629
5	New York	577
6	Ohio	545
7	Texas	498
8	Tennessee	473
9	Georgia	410
10	Colorado	394

TABLE 5. As in Table 4 for the least casualties.

Rank	State	No. of deaths and injuries
43	Delaware	42
44	Washington	40
45	Puerto Rico	36
46	North Dakota	35
47	Vermont	30
48	Oregon	26
49	District of Columbia	23
50	Nevada	18
51	Hawaii	4
52	Alaska	0

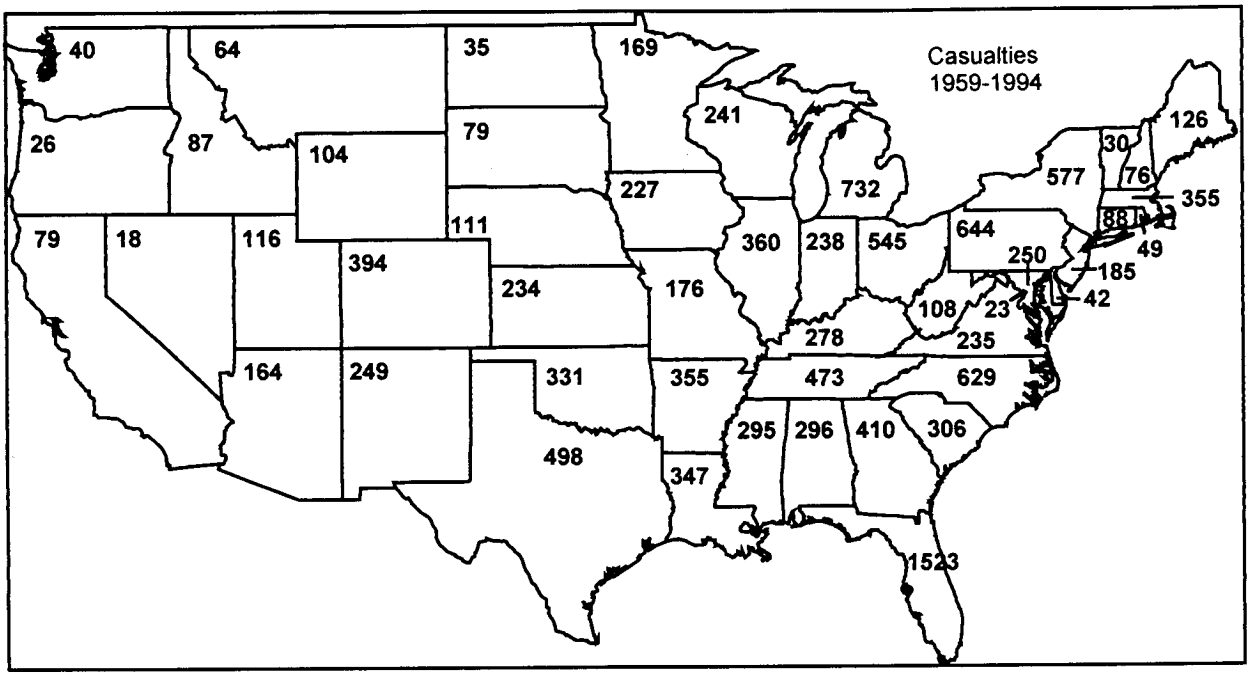

FIGURE 1. US map of number of lightning casualties (deaths and injuries combined) by state from 1959 to 1994.

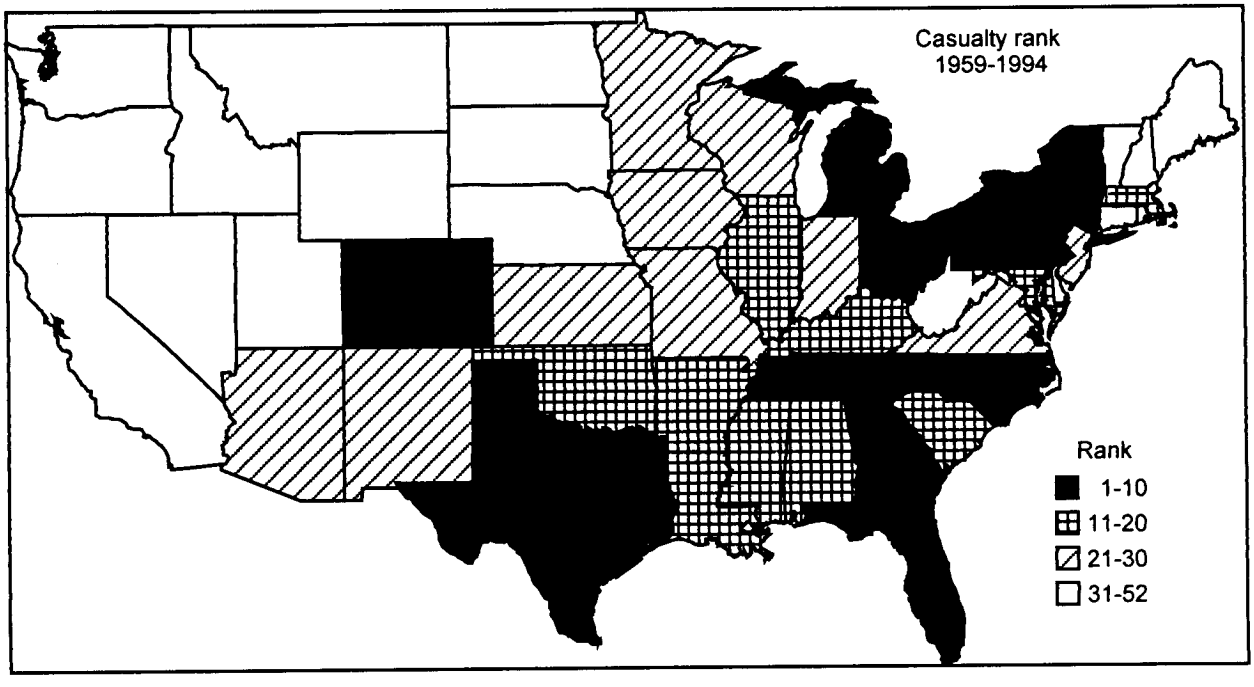

FIGURE 2. US map of lightning casualties (deaths and injuries combined) ranked by state from 1959 to 1994.

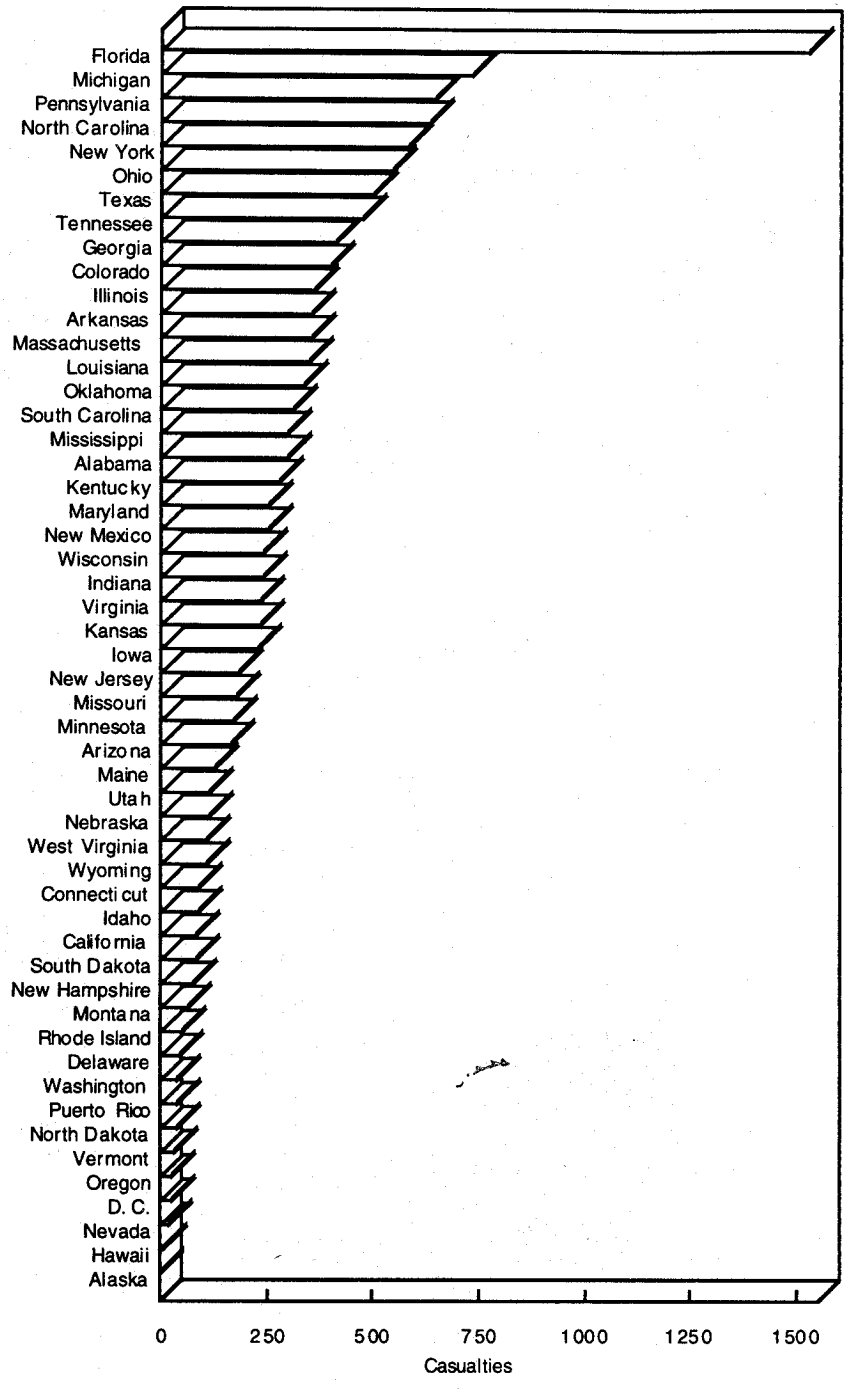

FIGURE 3. Number of lightning casualties (deaths and injuries combined) ordered by state from 1959 to 1994.

B. DEATHS

Maps of lightning-caused fatalities are shown in Figures 4 and 5, and states with the most and least deaths in Tables 6 and 7. Florida has twice as many deaths compared to any other state in *Storm Data*.

A major change from previous results for casualties is the absence of Michigan in the highest totals of deaths (Table 6), indicating that injuries have been more commonly-reported than deaths in Michigan. Otherwise, the same states are in the first-ten list for both deaths and casualties, although in a different order. Also, Maryland and Arkansas for deaths replace Georgia and Colorado on the casualty list. The large Maryland entry is mainly due to the 81 deaths in a lightning-caused aircraft crash in 1963.

In terms of the least lightning-caused fatalities, there were no deaths in Hawaii and Alaska. The bottom-ten list in Table 7 includes the same states as casualties (Table 5), except New Hampshire and Rhode Island replace Delaware and Puerto Rico.

Lightning deaths from *Storm Data* at specific locations in the US were shown from 1959 to 1965 by Zegel (1967). *Storm Data* deaths were plotted by state in Mogil et al. (1977) for 1968 to 1976, and Duclos and Sanderson (1990) for 1968 to 1985.

Pakiam et al. (1981) plotted each fatality on a map of Singapore. Coates et al. (1993) for Australia and Gourbiere et al. (1997) for France showed maps of lightning deaths divided by political boundaries in formats similar to Figure 5. In the US, state maps of lightning deaths by county have been compiled for North Carolina (Langley et al., 1991), Michigan (Ferrett and Ojala, 1992), and Colorado (López et al., 1995).

There were 3239 *Storm Data* deaths in the US from 1959 to 1994 (Table 3 and Figures 4 and 5) for an average of 90 per year. The same analysis can be made for deaths using the network-detected ground strikes as in the previous section for casualties. The result is one death for every 345,000 flashes in the US.

TABLE 6. Ten US locations with the most deaths due to lightning from 1959-1994 in *Storm Data*.

Rank	State	Number of deaths
1	Florida	345
2	North Carolina	165
3	Texas	164
4	New York	128
5	Tennessee	124
6	Louisiana	116
7	Maryland	116
8	Ohio	115
9	Arkansas	110
10	Pennsylvania	109

TABLE 7. Ten US locations with the least deaths due to lightning from 1959-1994 in *Storm Data*.

Rank	State	Number of deaths
43	Vermont	12
44	North Dakota	11
45	New Hampshire	8
46	Oregon	7
47	Nevada	6
48	District of Columbia	5
49	Rhode Island	4
50	Washington	3
51	Alaska	0
52	Hawaii	0

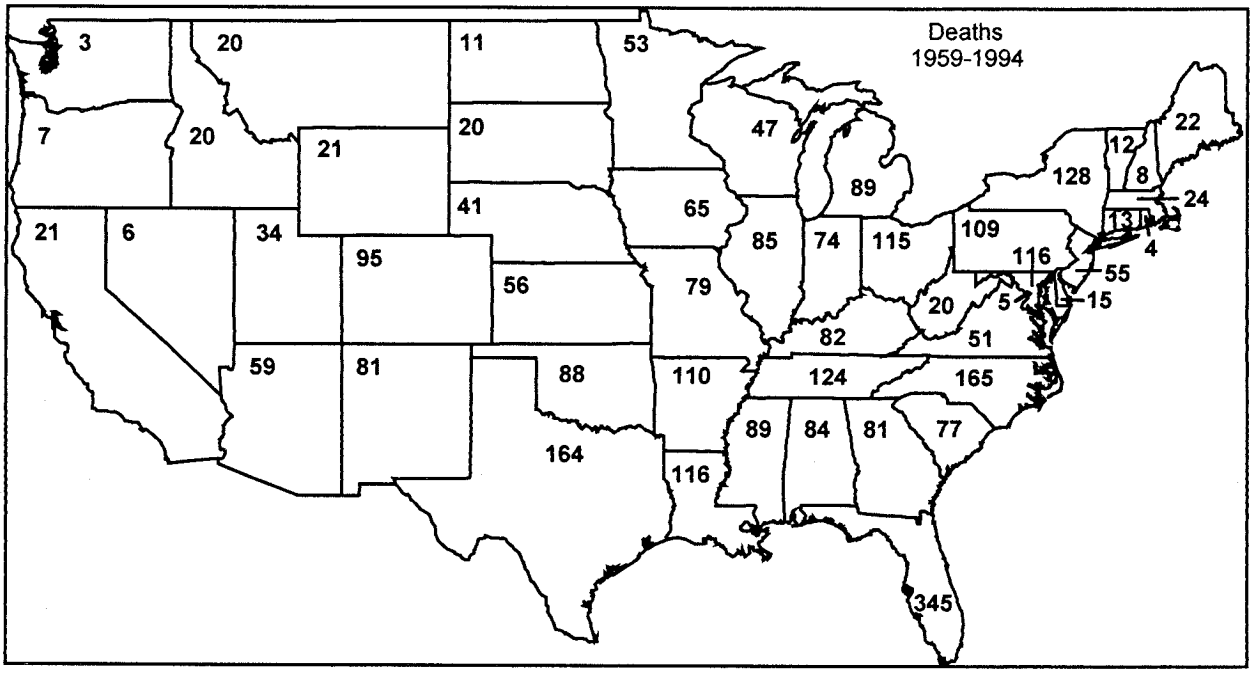

FIGURE 4. US map of number of lightning deaths by state from 1959 to 1994.

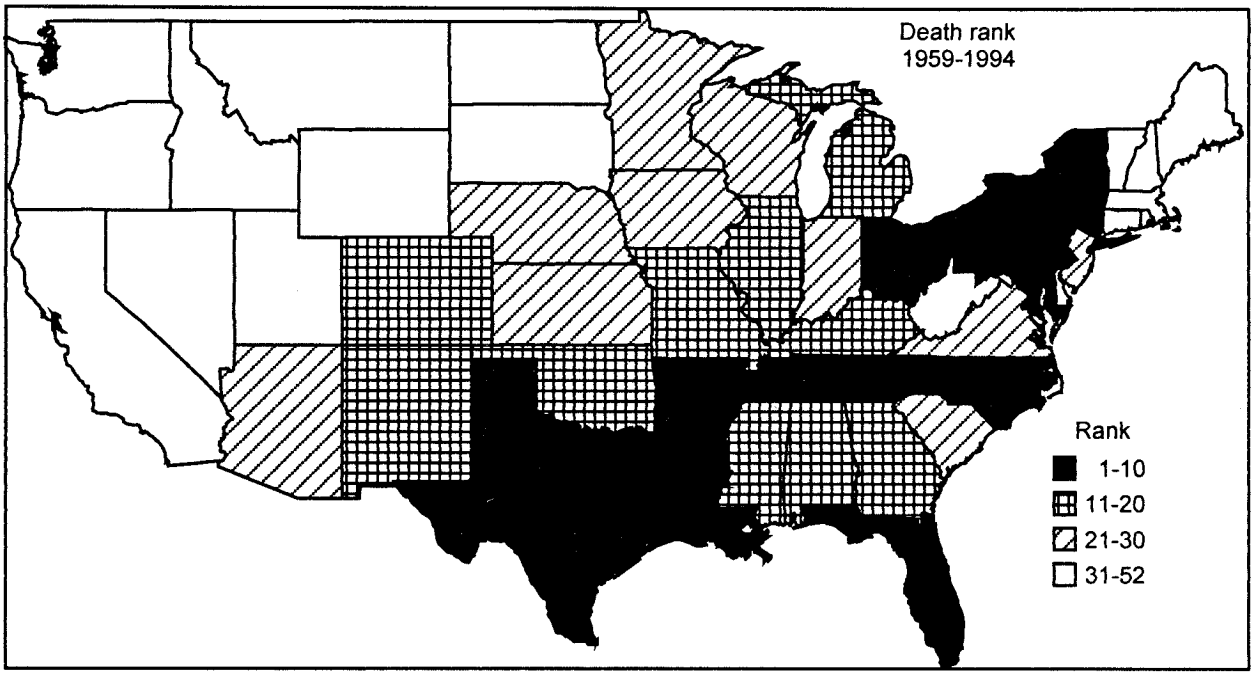

FIGURE 5. US map of lightning deaths ranked by state from 1959 to 1994.

C. INJURIES

Figures 6 and 7 show maps of injuries by state. Locations with the most and least injuries are in Tables 8 and 9. Florida had more injuries than any other state since 1959, as well as deaths (Table 6) and casualties (Table 4). For example, there were 105 injuries in Florida in 1996 alone (Paxton and Morales, 1997).

The same states appear on the first-ten list of fatalities in Table 8 except for two changes. Michigan is second in injuries but twelfth in deaths. Also, Georgia and Massachusetts on the injury list replace Arkansas and Maryland on the fatality list. The least injuries are in Alaska (0), Hawaii (4), Puerto Rico (6), and other western states and small eastern states.

The large number of Michigan injuries is due in part to two exceptional events (Ferrett and Ojala, 1992). During one *Storm Data* case in August 1975, 90 people were injured when lightning struck near the center of a campground at Leslie, Michigan. In June 1979, 45 National Guard soldiers suffered minor injuries when lightning struck their camp near Grayling, Michigan. A US map of injuries was shown for 1968 to 1976 by Mogil et al. (1977), and a state map of injuries by Colorado county was compiled by López et al. (1995).

Most states have more injuries than deaths; the US average ratio is 2.54 injuries per death in *Storm Data* from 1959 to 1994. But Missouri had only slightly more injuries (93) than deaths (78), and Puerto Rico had 6 injuries but 30 deaths; a few other locations approach a 1:1 ratio. A map of the injury to death ratio by state (not shown) has no pattern. In Puerto Rico, the authors found that many lightning injuries occur there but are not widely known, while deaths are usually reported to the National Weather Service and included in *Storm Data*. A low ratio of injuries to fatalities may indicate underreporting of injuries, such that deaths are better reported. López et al. (1993) found a greater underreporting of injuries requiring hospitalization (42%) than underreporting of deaths (28%) in Colorado.

There were 9818 *Storm Data* injuries in the US from 1959 to 1994 (Table 3 and Figures 6 and 7). The same analysis for injuries using network-detected lightning as in previous sections results in one US injury for every 114,000 flashes.

TABLE 8. Ten US locations with the most injuries due to lightning from 1959-1994 in *Storm Data.*

Rank	State	Number of injuries
1	Florida	1178
2	Michigan	643
3	Pennsylvania	535
4	North Carolina	464
5	New York	449
6	Ohio	430
7	Tennessee	349
8	Texas	334
9	Massachusetts	331
10	Georgia	329

TABLE 9. Ten US locations with the least injuries due to lightning from 1959-1994 in *Storm Data.*

Rank	State	Number of injuries
43	Washington	37
44	Delaware	27
45	North Dakota	24
46	Oregon	19
47	Vermont	18
48	District of Columbia	18
49	Nevada	12
50	Puerto Rico	6
51	Hawaii	4
52	Alaska	0

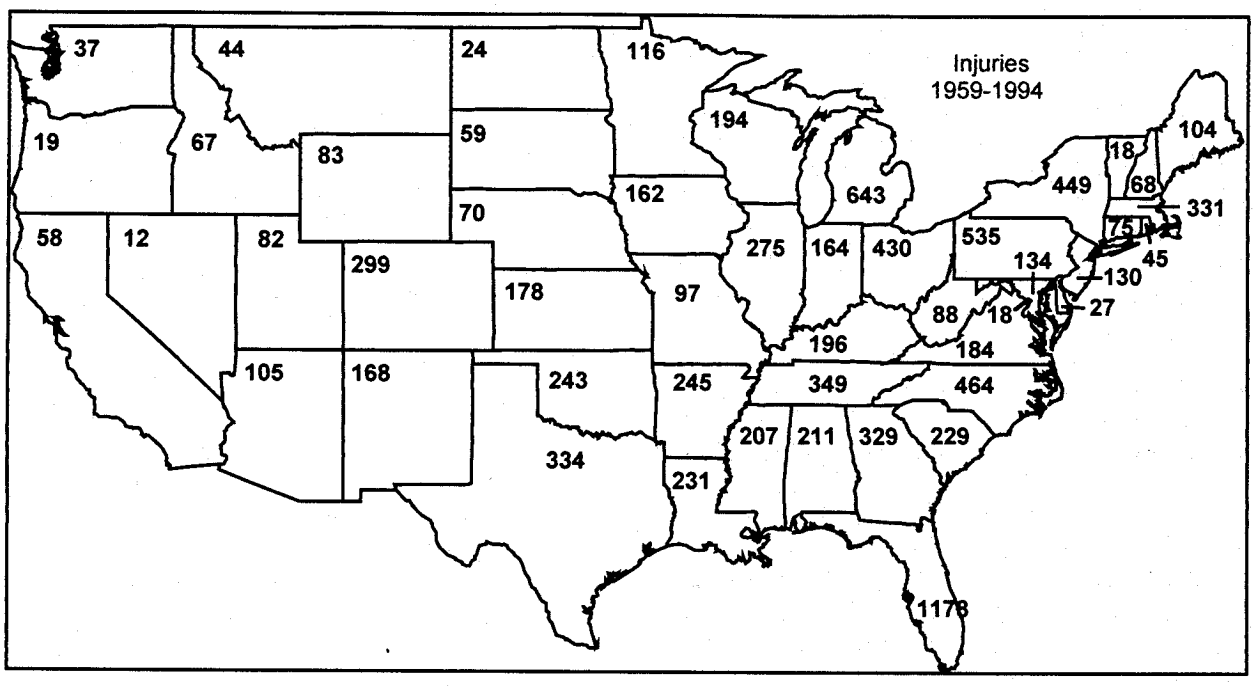

FIGURE 6. US map of number of lightning injuries by state from 1959 to 1994.

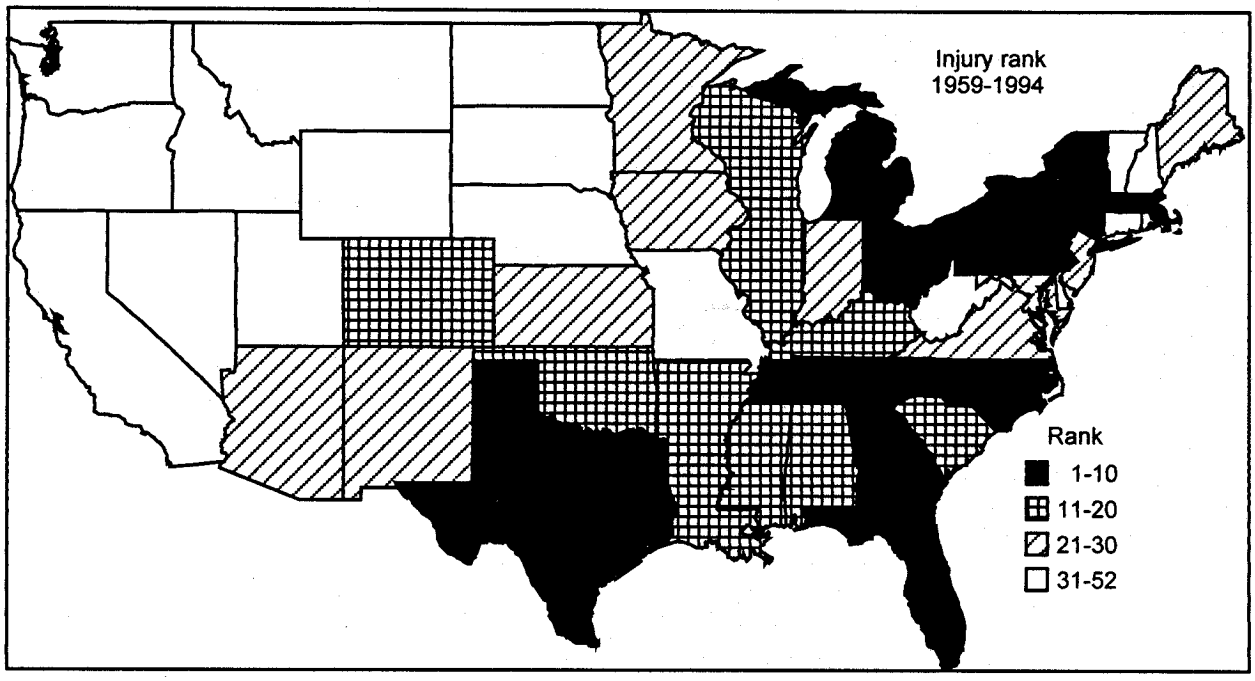

FIGURE 7. US map of lightning injuries ranked by state from 1959 to 1994.

D. DAMAGE REPORTS

Maps of damage reports are in Figures 8 and 9 by state. Locations with the most and least damage reports are in Tables 10 and 11.

It is apparent that damage reports in *Storm Data* are distributed very differently than are deaths and/or injuries. A high concentration of damage reports is evident over the plains from South Dakota to Texas. The highest number of damage reports is from Pennsylvania, where less than half as many casualties were reported as in Florida. In contrast, Florida is first on all casualty lists but is not high on the list of damages. Seven of the ten states with the highest damage counts are on the first-ten lists for casualties, deaths, or injuries. While Kansas, Oklahoma, and South Carolina rank in the first eight for damages, they are not in the top-ten list for any casualty category.

The least damage reports are from Alaska (3), Puerto Rico (4), and many of the same locations as in the casualty lists. An exception is the small number of damage reports from New Mexico, a state with a high number of deaths (Figure 4).

In the US, state maps of lightning damages by county have been compiled for Michigan (Ferrett and Ojala, 1992), Colorado (López et al., 1995), and Colorado, Utah and Wyoming (Holle et al., 1996).

There is a weakly-defined geographical pattern (not shown) in the ratio of damage reports to casualties in *Storm Data*. The damage/casualty report ratio was near one, or less, in all southwestern states, and several southeastern states including Florida. The northwest half of the US tended to have nearly two damage reports for every casualty report. Whether the ratio is influenced by accurate reporting of every death or injury, or whether the reporting system in some states is not very complete in reporting damages is unknown.

It is also unknown why there should be any pattern since damage reports are so greatly underreported (Section 2). Damage reports in *Storm Data* are underreported by as much as 367:1, as described in Section 2 based on insurance claims in Holle et al. (1996). Therefore, rates of flashes per damage report cannot be made reliably from the available database as was done for casualties, deaths, and injuries in previous sections.

TABLE 10. Ten US locations with the most damage reports due to lightning from 1959-1994 in *Storm Data*.

Rank	State	Number of damage reports
1	Pennsylvania	1441
2	Kansas	1182
3	New York	1005
4	North Carolina	960
5	Oklahoma	826
6	Michigan	814
7	Tennessee	764
8	South Carolina	717
9	Texas	689
10	Georgia	656

TABLE 11. Ten US locations with the least damage reports due to lightning from 1959-1994 in *Storm Data*.

Rank	State	Number of damage reports
43	Arizona	84
44	Delaware	83
45	California	60
46	Washington	56
47	New Mexico	54
48	District of Columbia	14
49	Hawaii	14
50	Nevada	11
51	Puerto Rico	4
52	Alaska	3

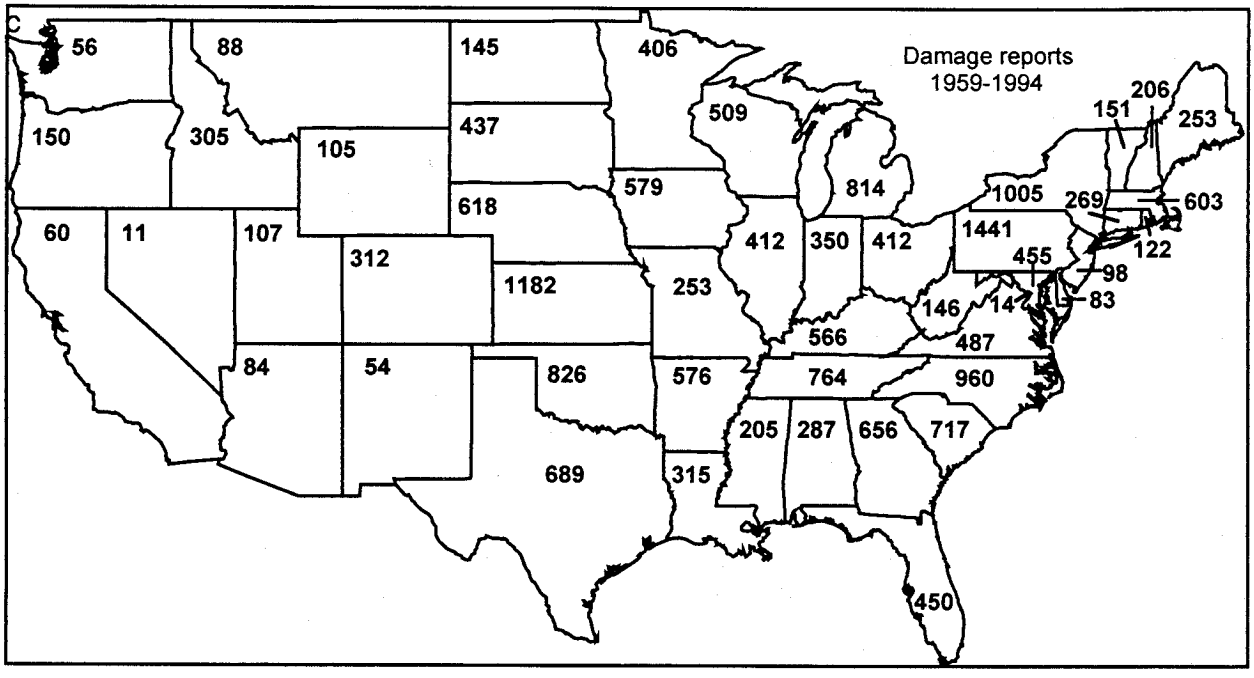

FIGURE 8. US map of number of lightning damage reports by state from 1959 to 1994.

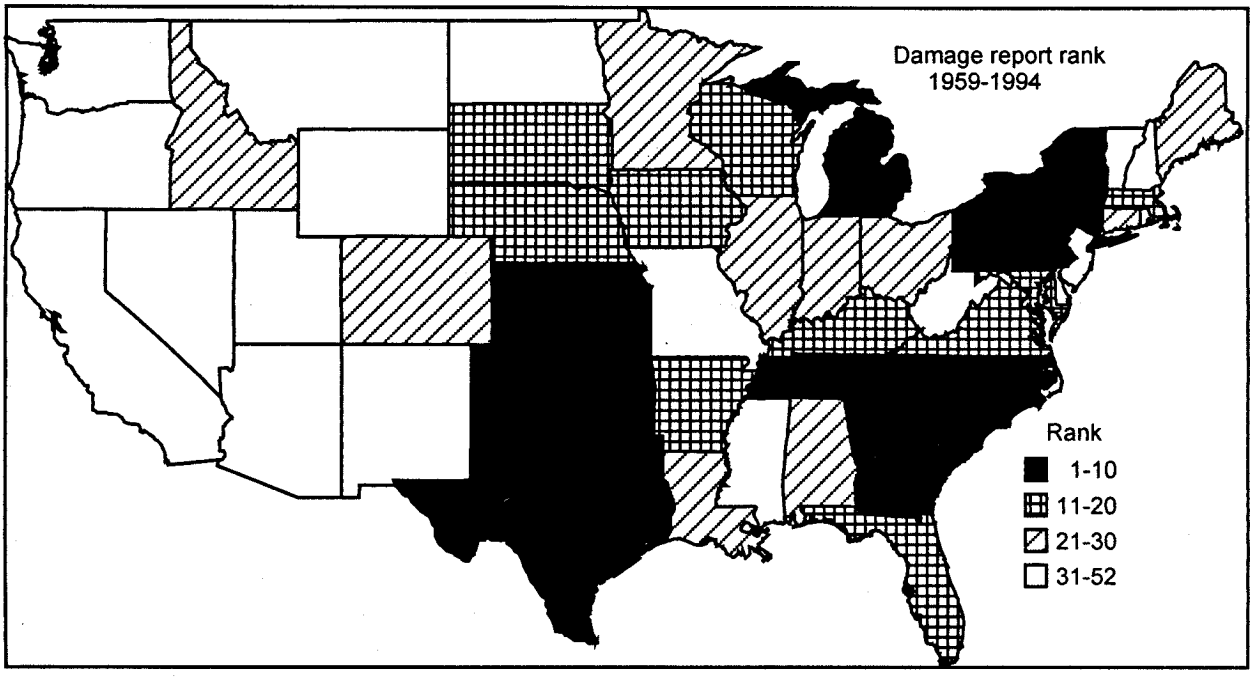

FIGURE 9. US map of lightning damage reports ranked by state from 1959 to 1994.

E. SUMMARY

Table 12 provides the detailed list of reported frequencies and corresponding ranks of fatalities, injuries, casualties, and damage reports for all states and other locations in the dataset. Information in this table was used to develop the preceding maps and tables.

Florida led the nation in deaths, injuries, and therefore casualties, over all other locations by a wide margin. States with high numbers of casualties (Figures 1, 2) tended to be in the following categories:

- Florida--very frequent casualties and a sizable population.
- Southeast and southern plains--frequent casualties and medium to large populations (Alabama, Georgia, Mississippi, South Carolina, Tennessee, Texas).
- Midwest and northeast--densely populated (Michigan, New York, Ohio).
- Southern Rockies--less populated than many states (Arizona, Colorado, New Mexico).

The largest number of damage reports came from Pennsylvania, but it had less than half as many casualties as Florida. North Carolina had uniformly high frequencies in all categories – second in deaths, fourth in injuries, and fourth in damages. In contrast, Kansas was second in damage reports but twenty-fifth in deaths and twenty-second in injuries. There were a few locations, such as Alaska, Hawaii, Puerto Rico, the District of Columbia, and Nevada, with very few casualties and damage reports over the 36-year period.

Data from recent years collected by the US National Lightning Detection Network results in a rough estimate of one lightning casualty for every 86,000 flashes. A similar method gives an estimate of one death for about every 345,000 flashes, and an injury for about every 114,000 flashes.

4. VARIATIONS BY STATE WEIGHTED BY POPULATION

Section 3 showed results when actual frequencies of *Storm Data* entries were used. Many states with high frequencies of casualties and damage are the most populous, such as New York and other northeast states. However, some states such as Colorado and New Mexico are not so populous but also had large numbers of lightning-caused deaths and/or injuries.

To compensate for this effect, population was considered. Figure 10 shows the ranks by state of the population during the *Storm Data* record. These values were found by averaging the decennial census populations in 1960, 1970, 1980, and 1990. The average populations were then used to calculate rates of casualties, deaths, injuries and damages for each state.

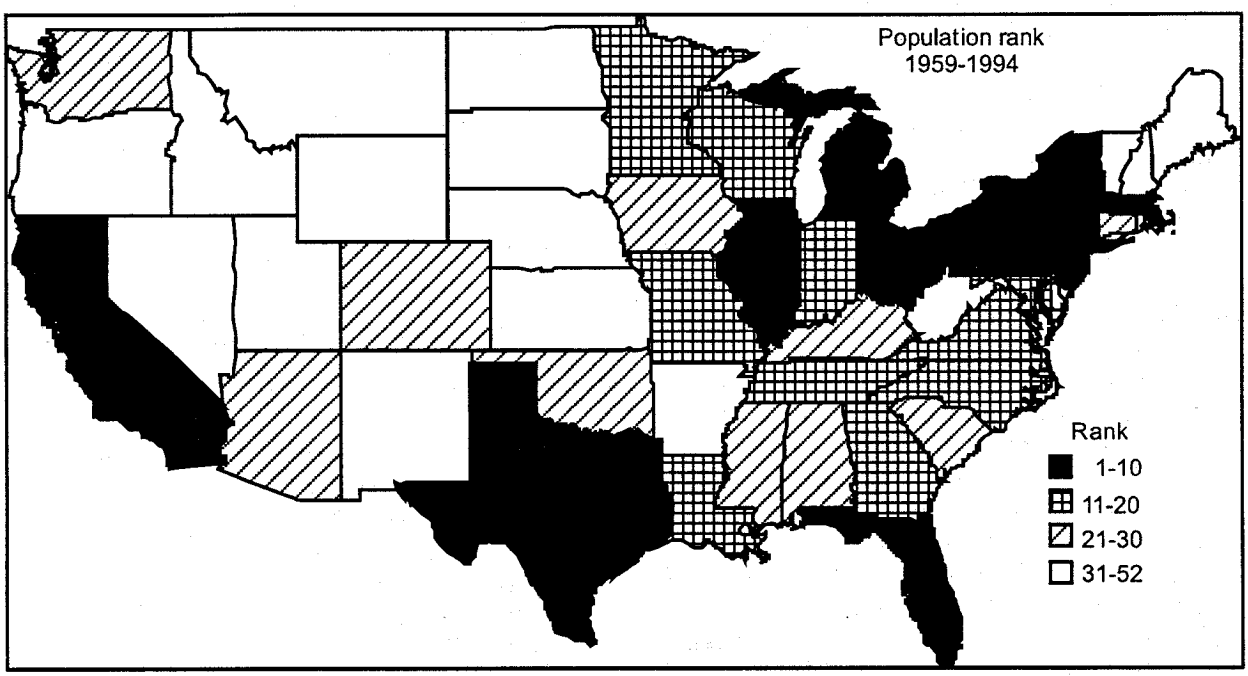

FIGURE 10. US map of average population ranked by state from 1959 to 1994.

A. DEATH AND INJURY (CASUALTY) RATE PER POPULATION

States with the highest rates of lightning-caused casualties per million people are shown in Figure 11 and Table 13. Table 14 lists the states with the lowest casualty rates.

There are major differences between these rates and reported frequencies of casualties in Figures 1 and 2, and Table 4. States are also shown in descending order by number of casualties per million people in Figure 12.

The highest rates of casualties were in Wyoming and New Mexico, while these states were only 35th and 21st, respectively, in actual reports. These states are less populous than most, but had many casualties. It must be noted that in section 5 of this paper, Wyoming will be shown to have had almost all of its casualties in the 1960s and 1970s, and almost none since then.

The only states in the first-ten list of both casualties and casualty rate (Table 4) are Florida, Colorado, and North Carolina. Florida was first in all previous lists of casualties, while it is third in casualty rate. Colorado was tenth in reported casualties, and fifth in casualty rate; North Carolina was fourth and tenth in rate.

The net effect of taking into account the population is a shift from the populous eastern states to the Rocky Mountain and plains states. Many of the southeast states have a high ranking in both Figures 2 and 11.

The lowest casualty rates in Table 14 continue to be in nearly the same locations. There is a dominance of west-coast states and small eastern states in the list of reports in Table 5 and casualty rate in Table 14.

Casualty rates for each state by population over the US were also shown by Ferrett and Ojala (1992) from 1959 to 1987, and López and Holle (1995) from 1959 to 1990. These studies categorized results by increments of casualty rates rather than the ranks in this report. López et al. (1995) showed casualty rates by county in Colorado.

Data from the National Lightning Detection Network can be used to take into account both population and lightning activity. For the US, a rate is found of 7.7 casualties per million people per 100 million flashes.

TABLE 13. Ten US locations with the highest rates of lightning-caused casualties (deaths and injuries combined) per million people from 1959-1994 in *Storm Data*.

Rank	State	Casualties/ million people/year
1	Wyoming	7.21
2	New Mexico	5.76
3	Florida	4.91
4	Arkansas	4.73
5	Colorado	4.28
6	Mississippi	3.47
7	Oklahoma	3.31
8	Maine	3.25
9	South Dakota	3.21
10	North Carolina	3.16

TABLE 14. As in Table 13 for lowest casualty rates.

Rank	State	Casualties/ million people/year
43	Illinois	0.91
44	Connecticut	0.82
45	Nevada	0.76
46	New Jersey	0.71
47	Puerto Rico	0.44
48	Oregon	0.31
49	Washington	0.29
50	California	0.10
51	Hawaii	0.10
52	Alaska	0